Functional MRI:

Physics & Data Acquisition

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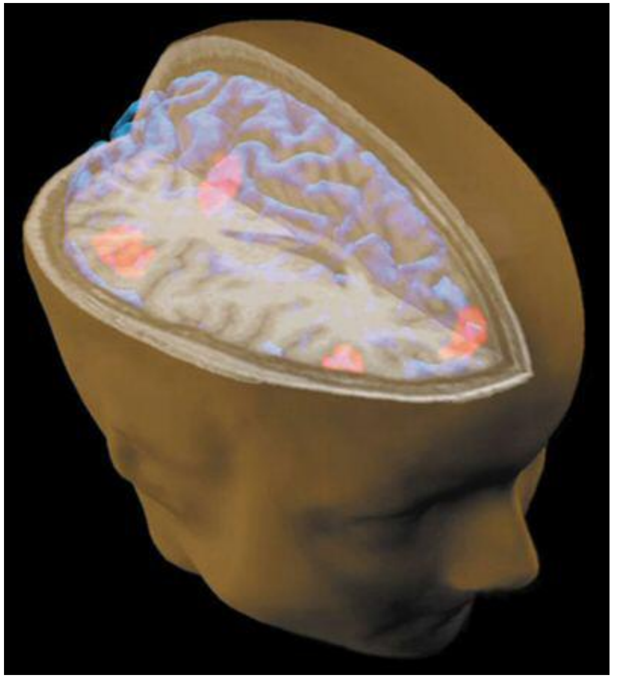

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- Advanced Medical Imaging Research Lab, Department of Biomedical Engineering, Amirkabir University of Technology, Tehran, Iran
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Education

Research Interests

- **Functional Neuroimaging (fMRI)**
- **MRI Physics & Pulse Sequence Developments**
- **Medical Signal & Image Processing**
- **Pattern Recognition & Neural Networks**
- **Digital Electronics**

Advisor: Dr. David G. Norris
Advisor: Dr. Gholam-Ali Hossein-Zadeh

- **Visiting Scholar**: Sep. 2015: Dec. 2016

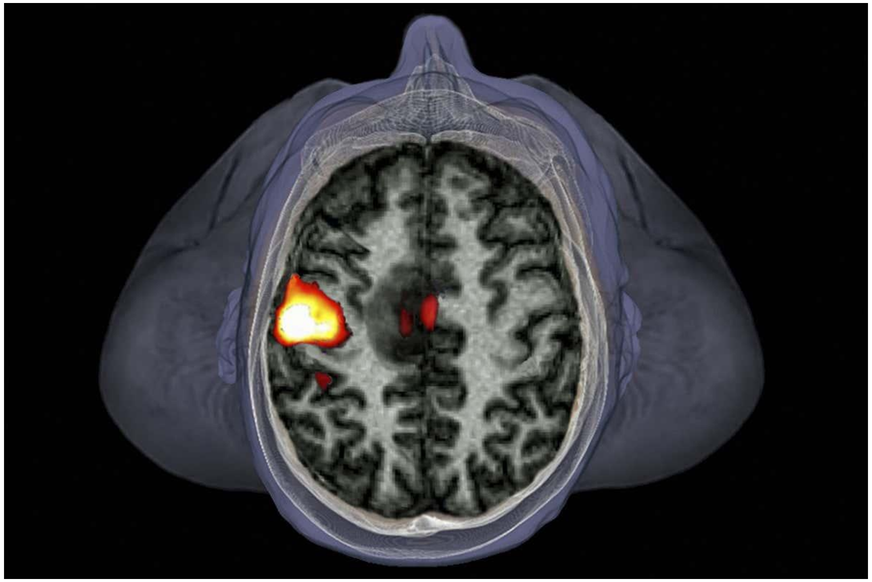
Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Nijmegen, Netherlands

Supervisor: Dr. David G. Norris

What is fMRI?

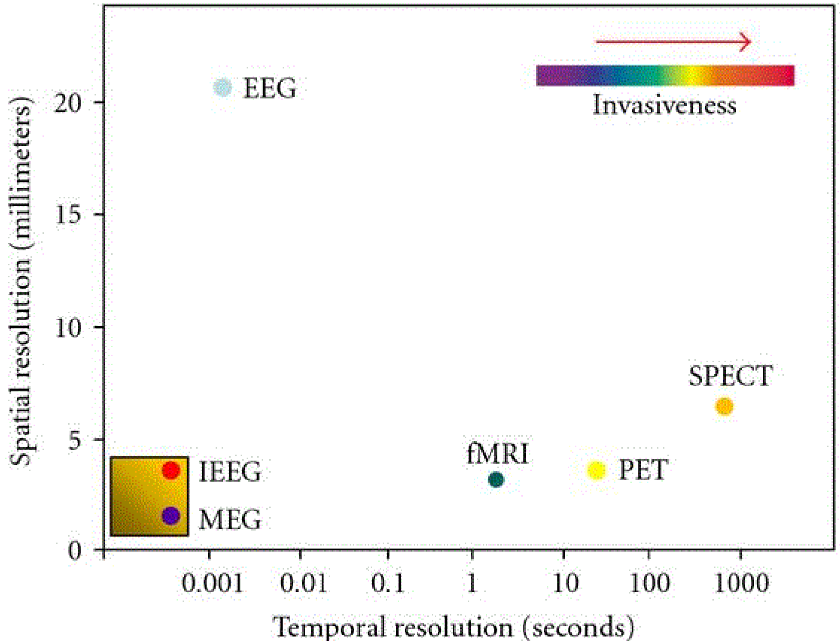
Functional **M**agnetic **R**esonance **I**maging

- fMRI is a non-invasive neuroimaging tool that determines neural activity within the brain using MRI scanner.



Why fMRI?

- Advantages
  - Non-invasive, no radiation
  - Spatial resolution
  - Easy for researchers to use



- Limitations
  - Expensive!
  - Metal free!
  - Time resolution (many have started to combine with EEG)
  - Need expert!

Rise of fMRI

Cumming, P. (2013) Neuroimage

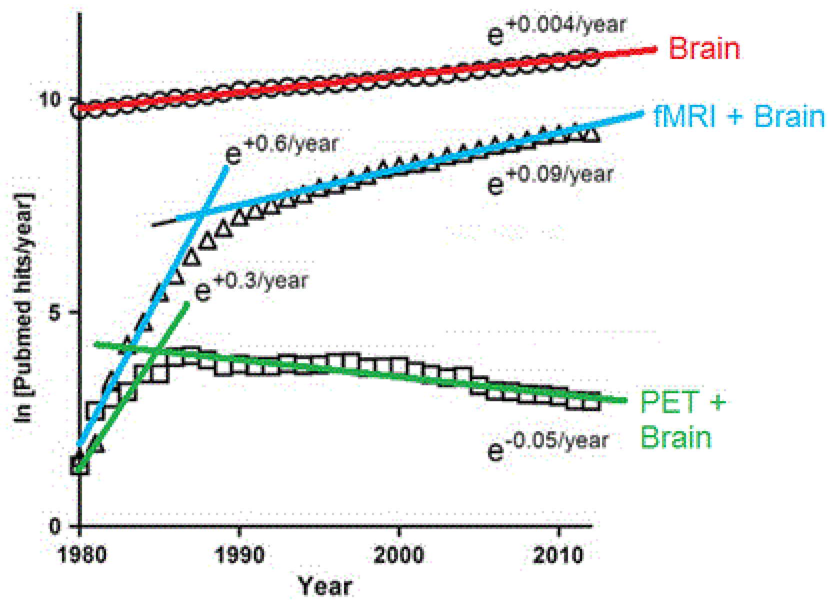
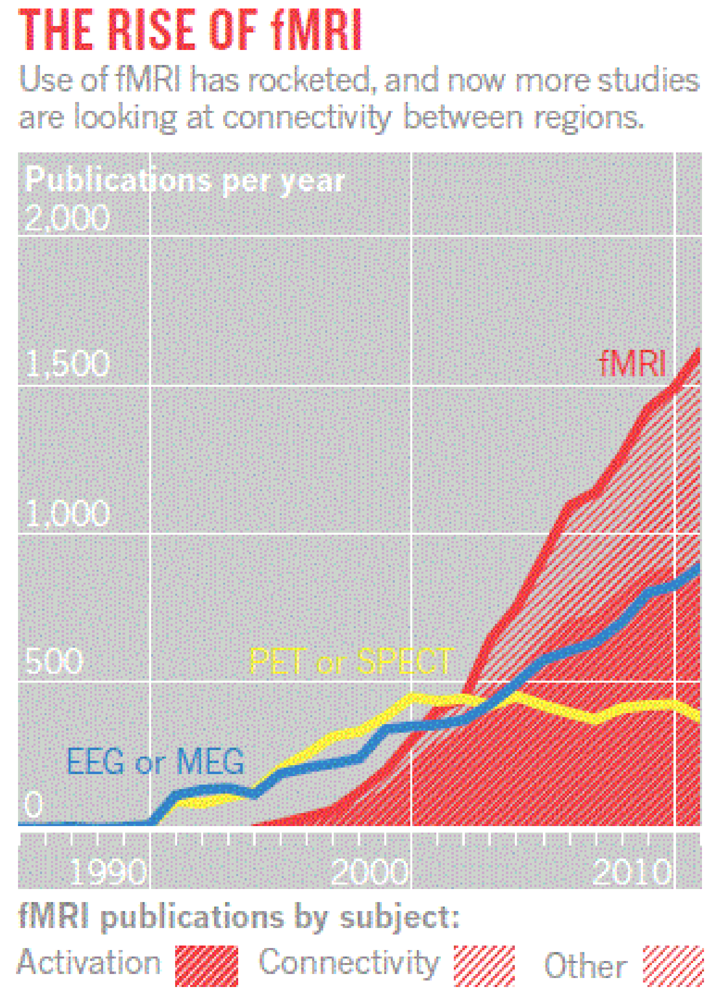


Fig. 1. ln transformation of hits per year for PubMed searches with items *Brain*, *fMRI + Brain*, and *PET + Brain*. Lines indicate regression slopes of linear phases, also expressed as exponents of e.

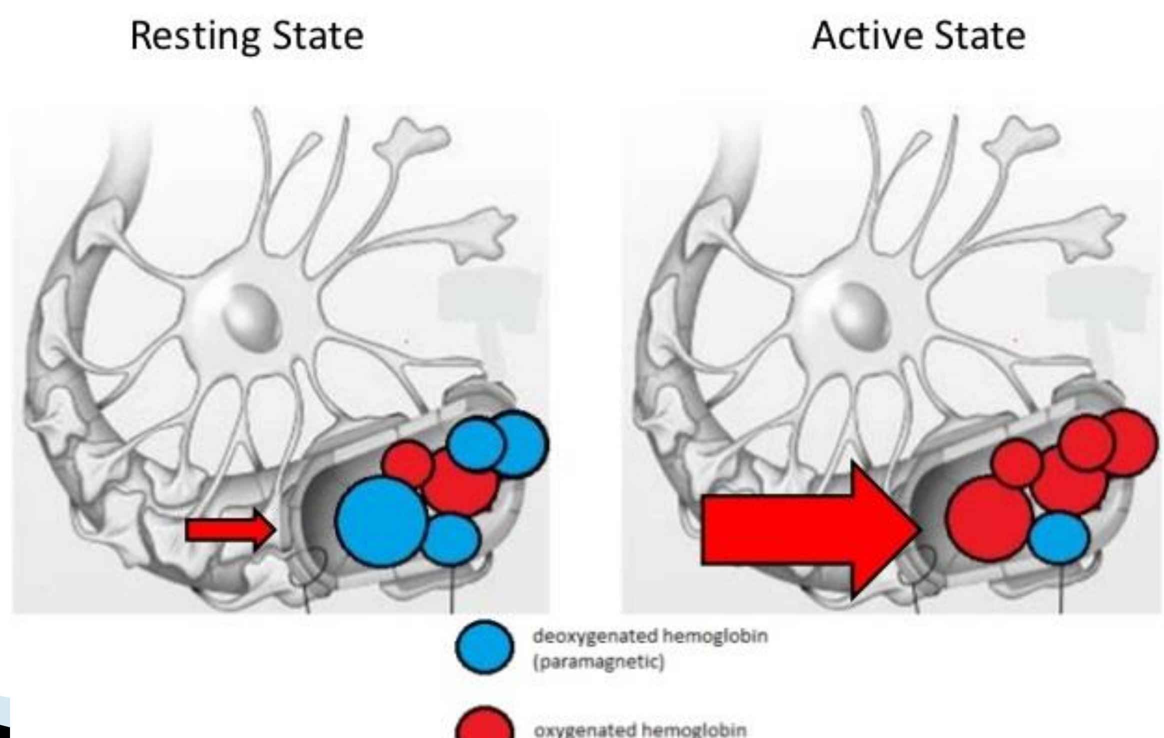
MRI Killed the radiotracers, By Neuroskeptic , August 30, 2013
www. discovermagazine.com



K. Smith, et al., *Functional magnetic resonance imaging is growing from showy adolescence into a workhorse of brain imaging.* Nature, 2012: VOL 484.

How does fMRI work?

- fMRI demonstrates brain activation by recording T2* signal changes due to increased blood oxygenation level, related to neural activity.



In the following …

- fMRI Physics
  - fMRI - Magnetic fields & spins
  - fMRI - Radio pulse & relaxation times
  - fMRI - Tissue contrasts
  - fMRI - BOLD & functional contrast

- fMRI Data Acquisition
  - Data Acquisition
  - Experimental Design
  - Areas for future research

What is MRI?

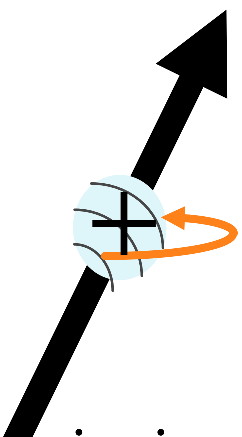
Magnetic Field in Scanner

- B0 = constant magnetic field
  - Strong and homogenous field
- Along z-axis
- Always ON!

1 Tesla = 20,000x Earth's magnetic field

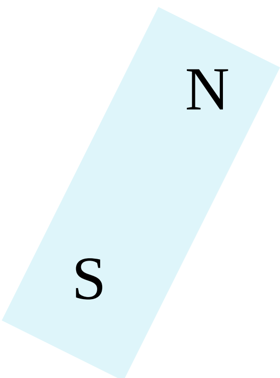
Spin

In particle physics, spin is an intrinsic form of angular momentum carried by elementary particles and atomic nuclei.



spinning proton

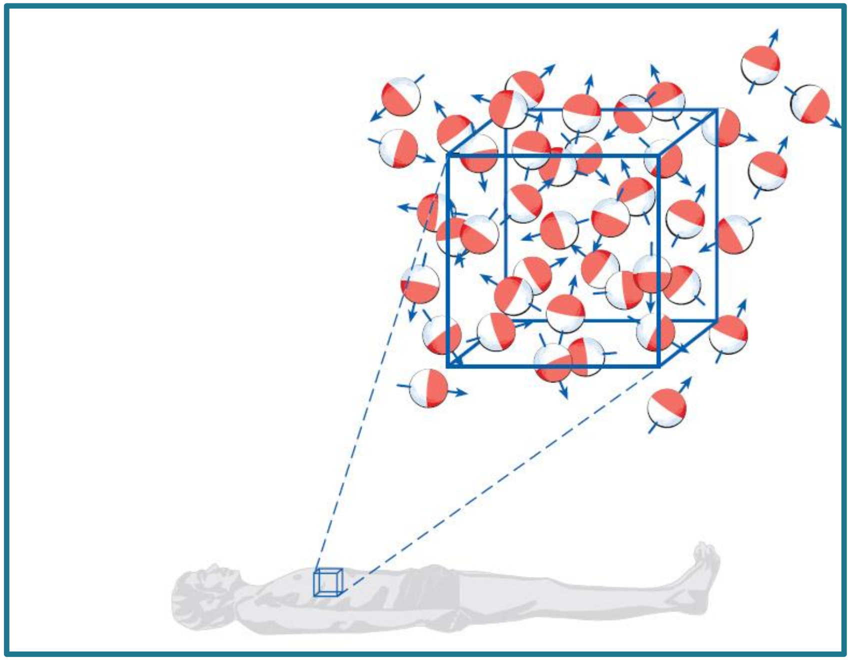
- Hydrogen protons spin producing a magnetic field
- A magnetic field creates an electrical charge when it rotates past a coil of wire



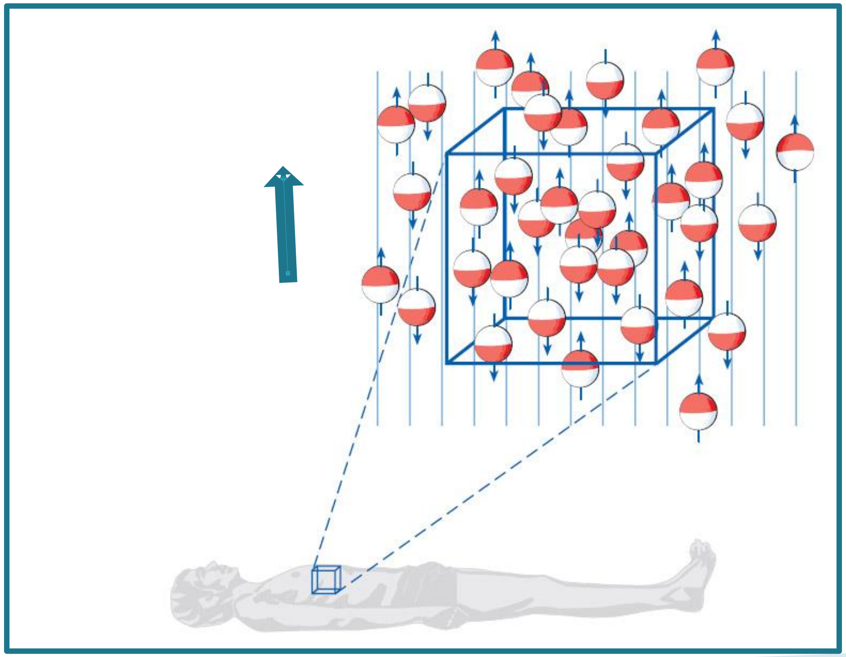
bar magnet

What happens in the scanner?

Outside scanner

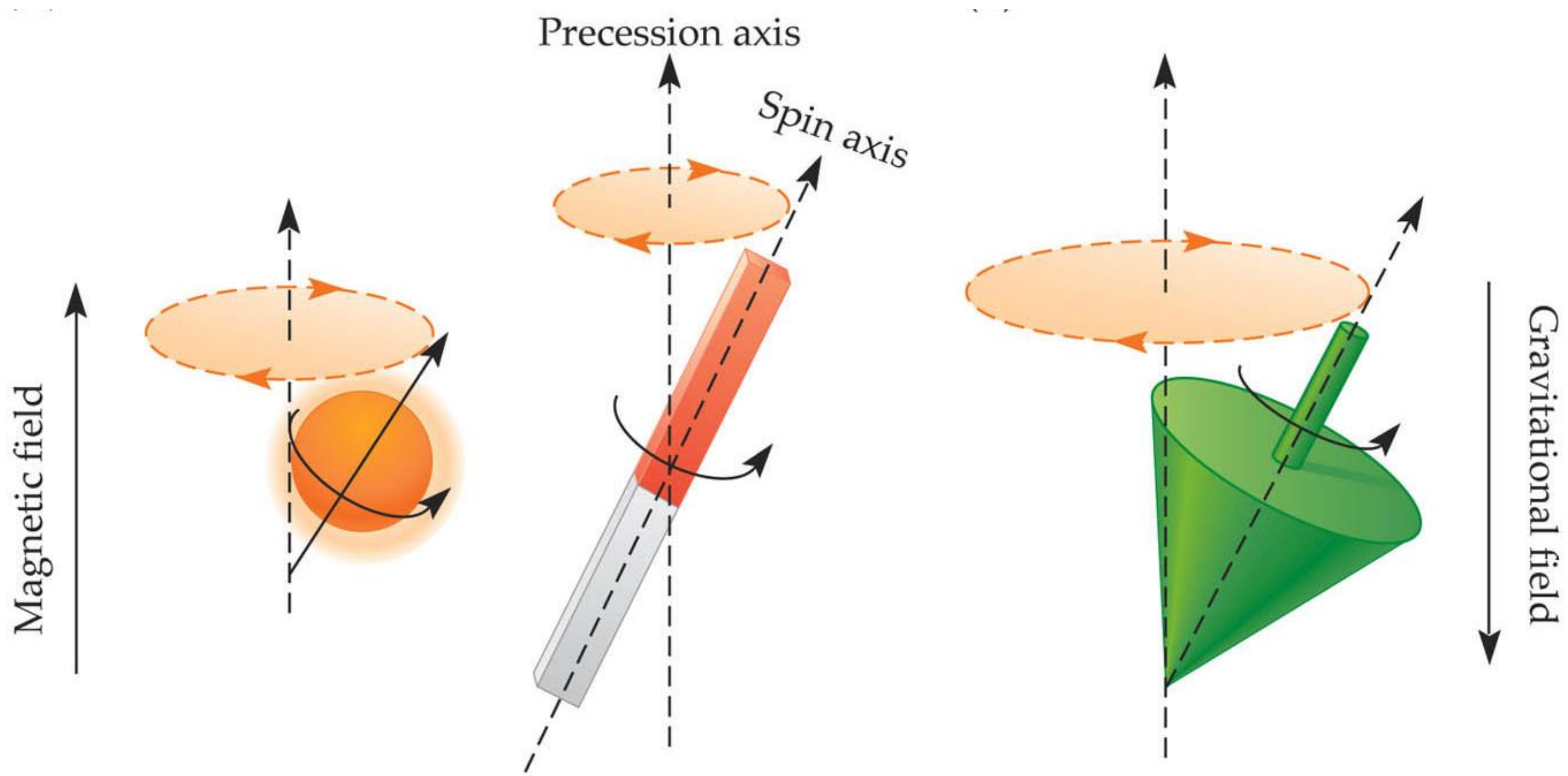


Inside scanner (B0)



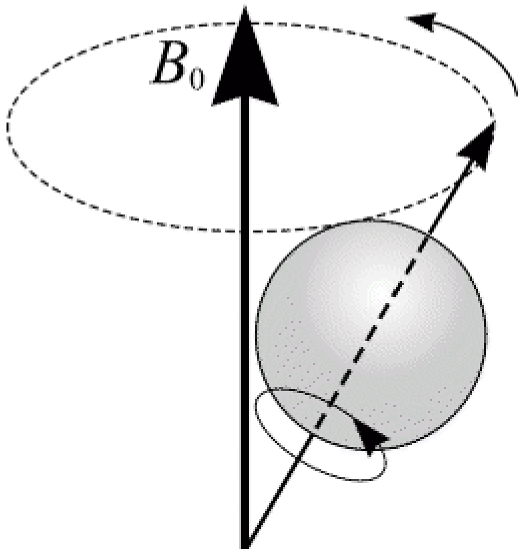
The protons of the H_2O molecules in our body align along B0

Precession in Magnetic Field



Precession & Larmor fr.

- Frequency of precession of magnetic moments given by **Larmor** relationship



$$\mathbf{f = \gamma \times B_0}$$

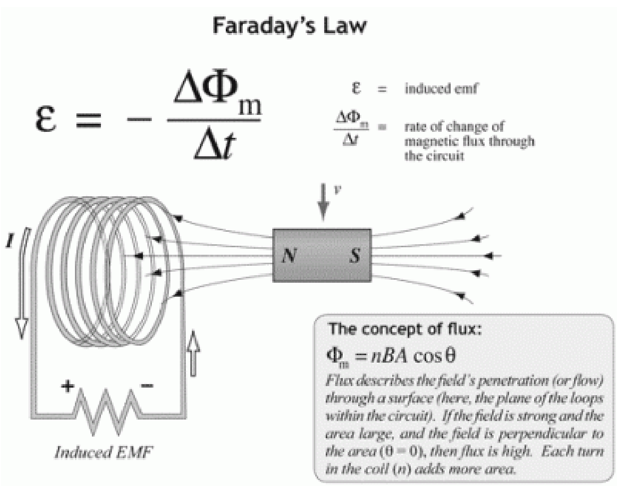
f = Larmor frequency (mHz)
γ = Gyromagnetic ratio (mHz/Tesla)
B_0 = Magnetic field strength (Tesla)

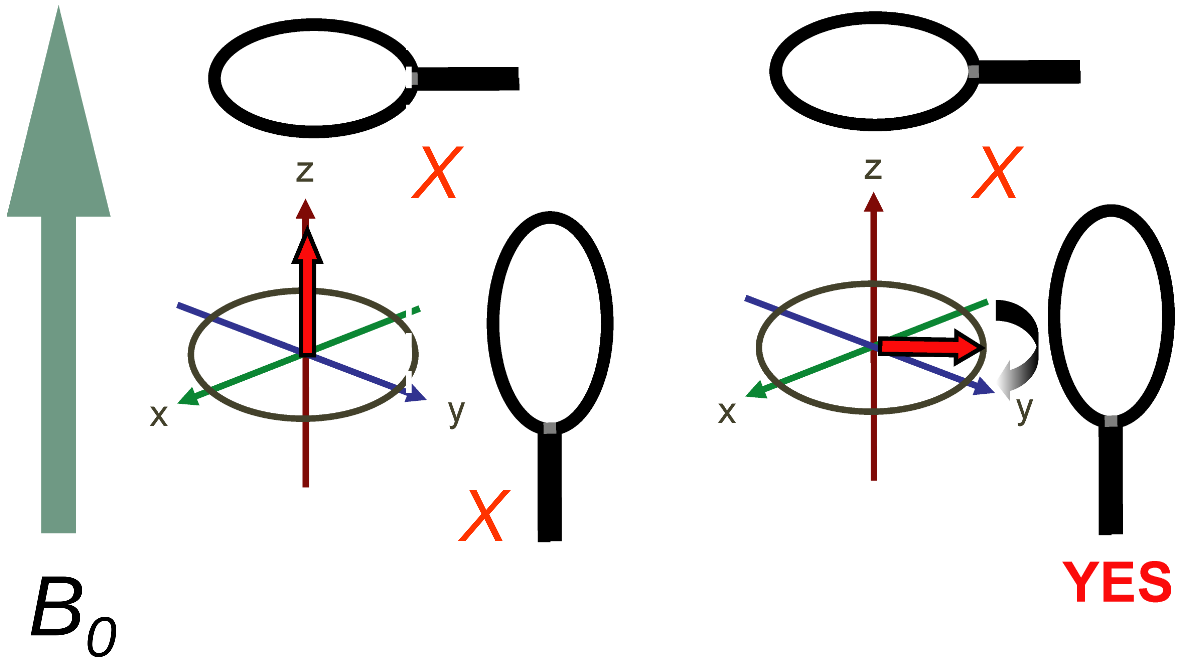
γ ~ 43 mHz/Tesla

<u>Larmor frequencies of RICs MRIs</u>

3T ~ 130 mHZ
7T ~ 300 mHz

Spin Excitation (B1)

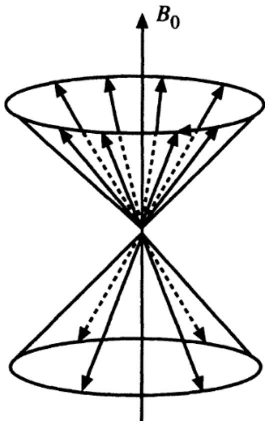




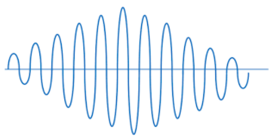
Magnetization vector does not precess => no induction in any coil

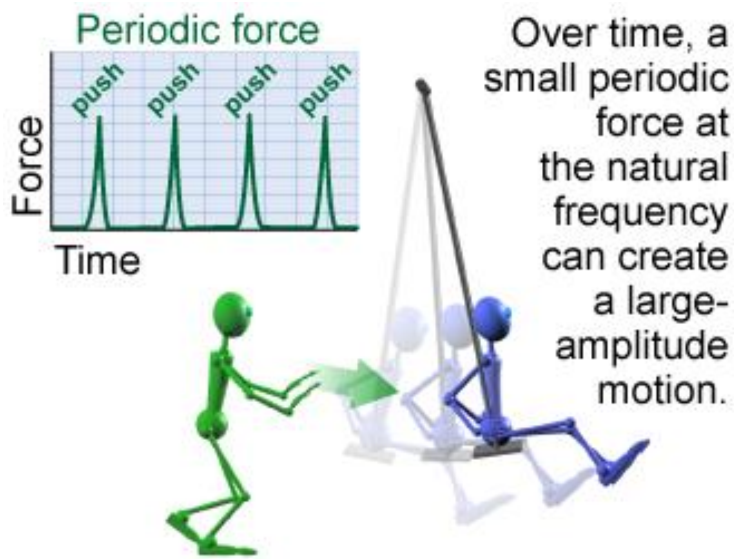
Transverse magnetization vector precesses about the main field => detected by a loop perpendicular to main field

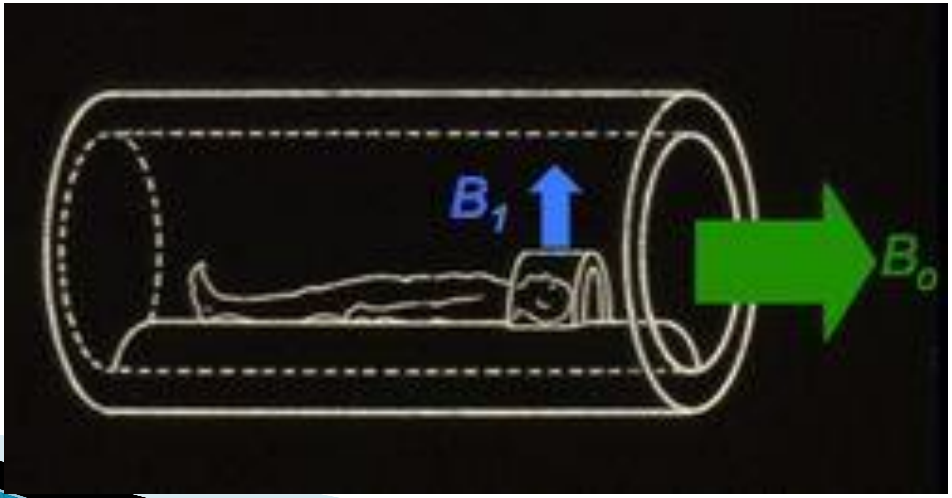
Spin Excitation (B1)



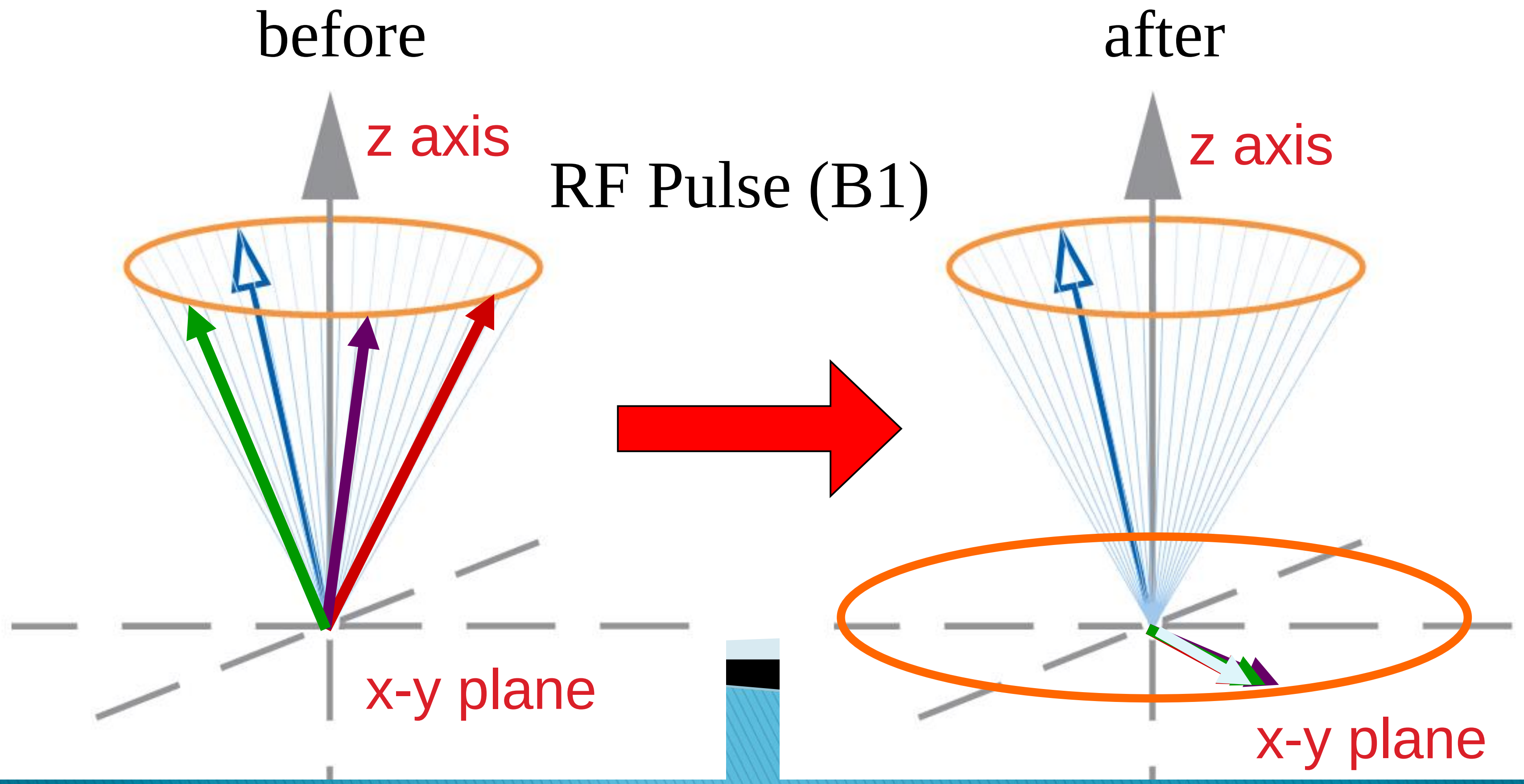
RF signal (B1)







What happens if spins fall down?



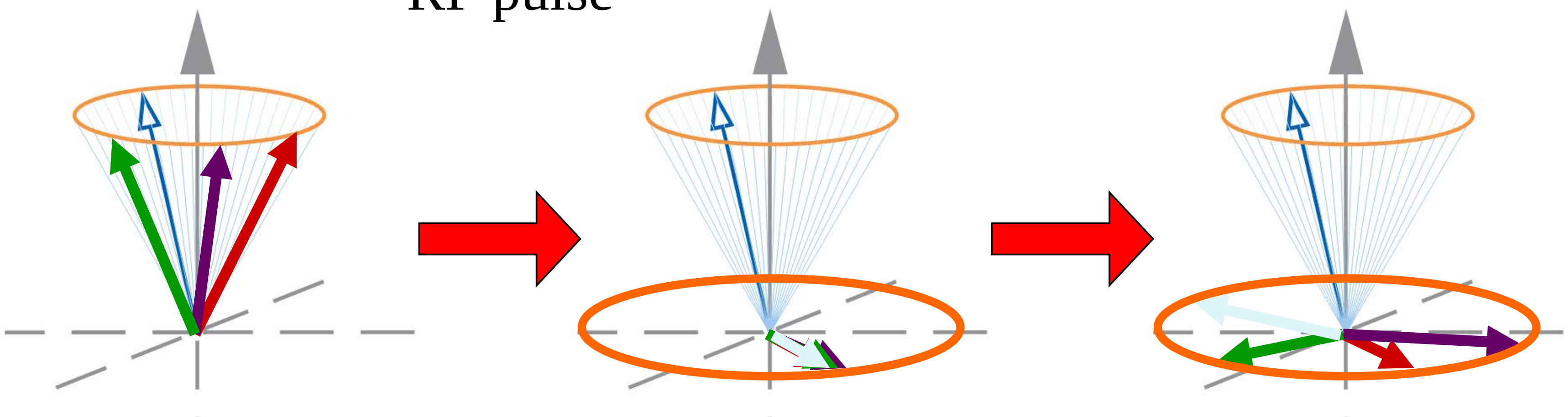
What is the T2 relaxation?

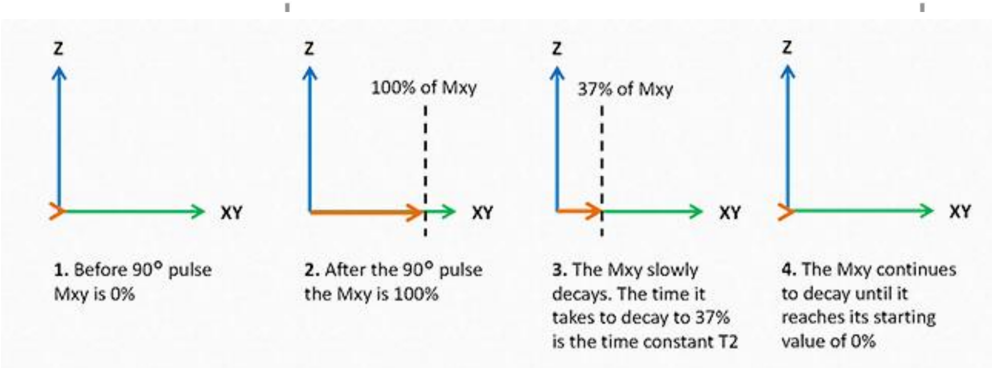
Dephasing in x-y plane = spin-spin relaxation

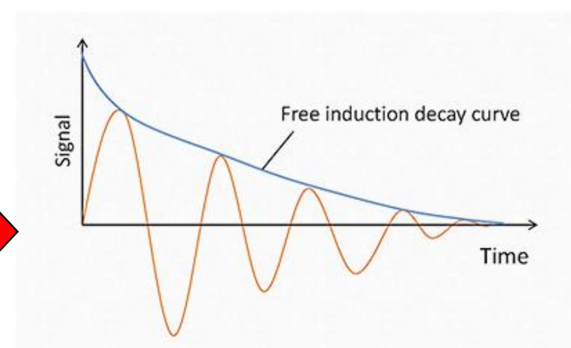
The Second Law of Thermodynamics

RF pulse

T2 relaxation

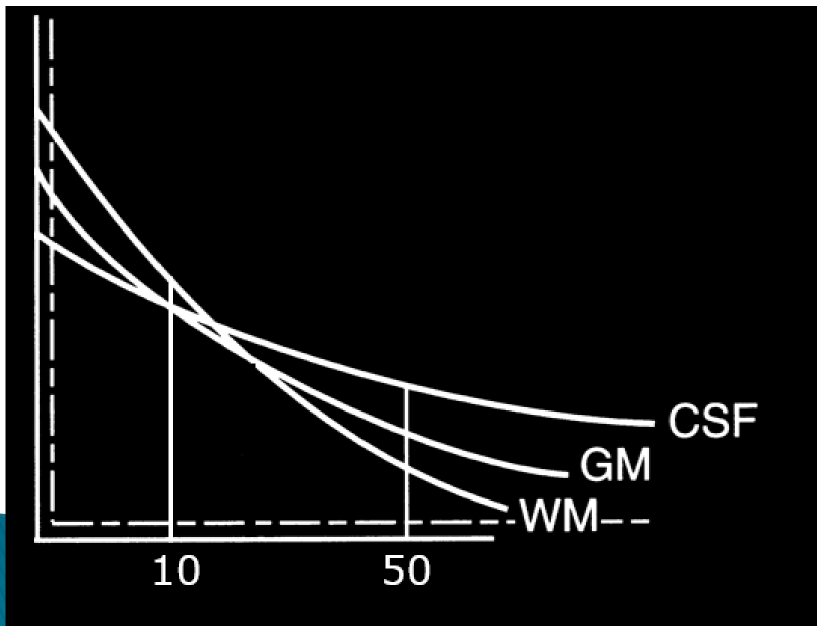




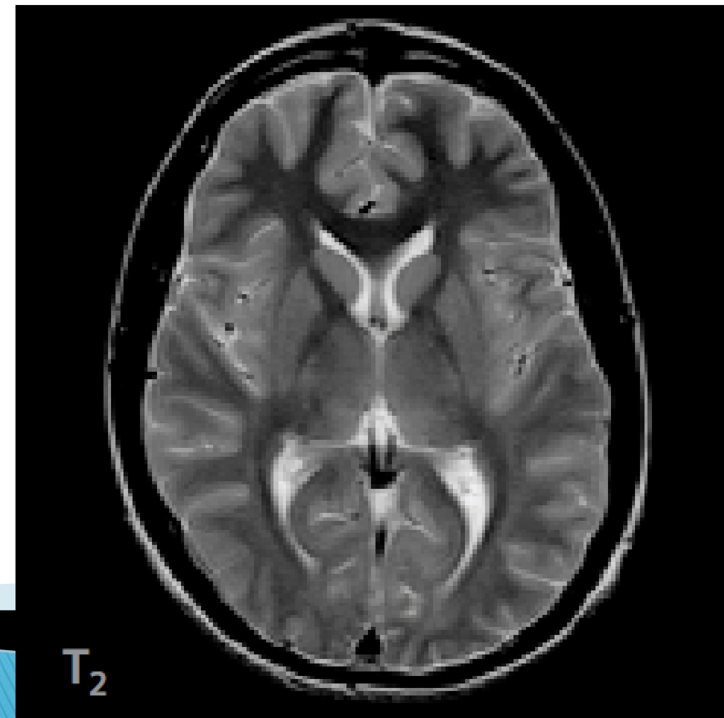


T2 Contrast

- Different tissues have different T2 relaxation times



TE (milliseconds)

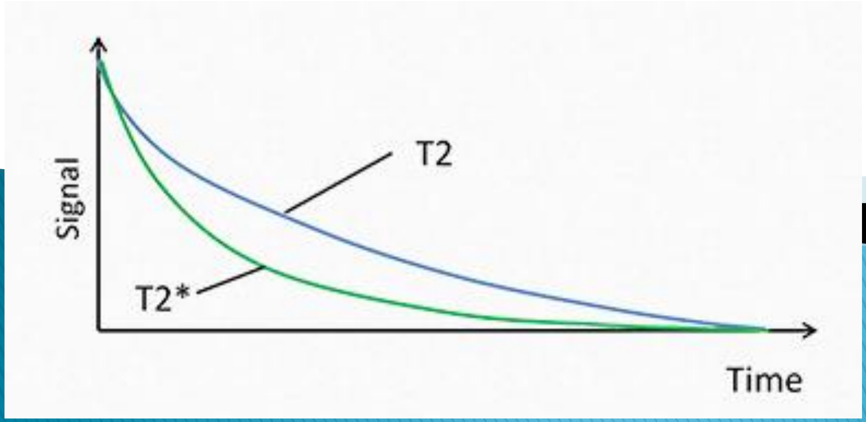


And what is T2*?

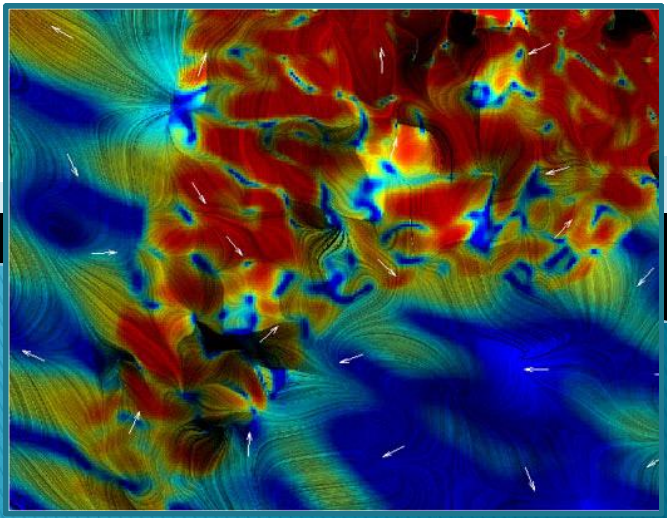
- Two reasons for dephasing in x-y plane
  - Spin-spin interaction → T2
  - Local magnetic field in-homogeneities → T2*

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \gamma \Delta B_0$$

T2(*) time constant

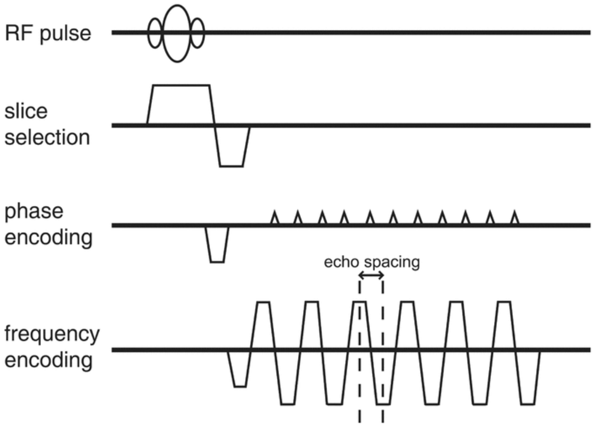


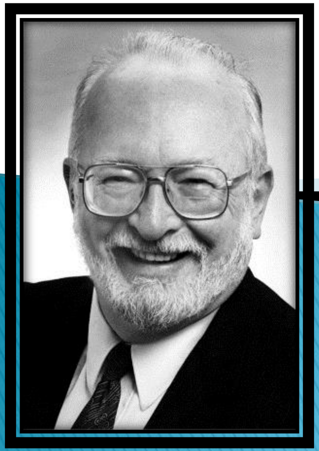
Magnetic field in-homogeneities

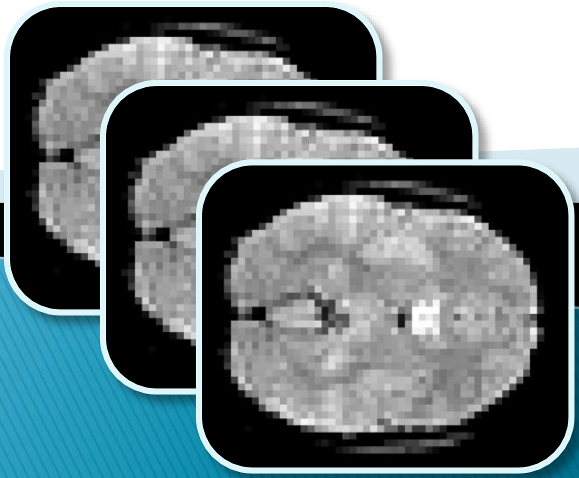


What about I in MRI?

- Too much to explain here
- Different gradients along magnetic field
- Lauterbur contribution

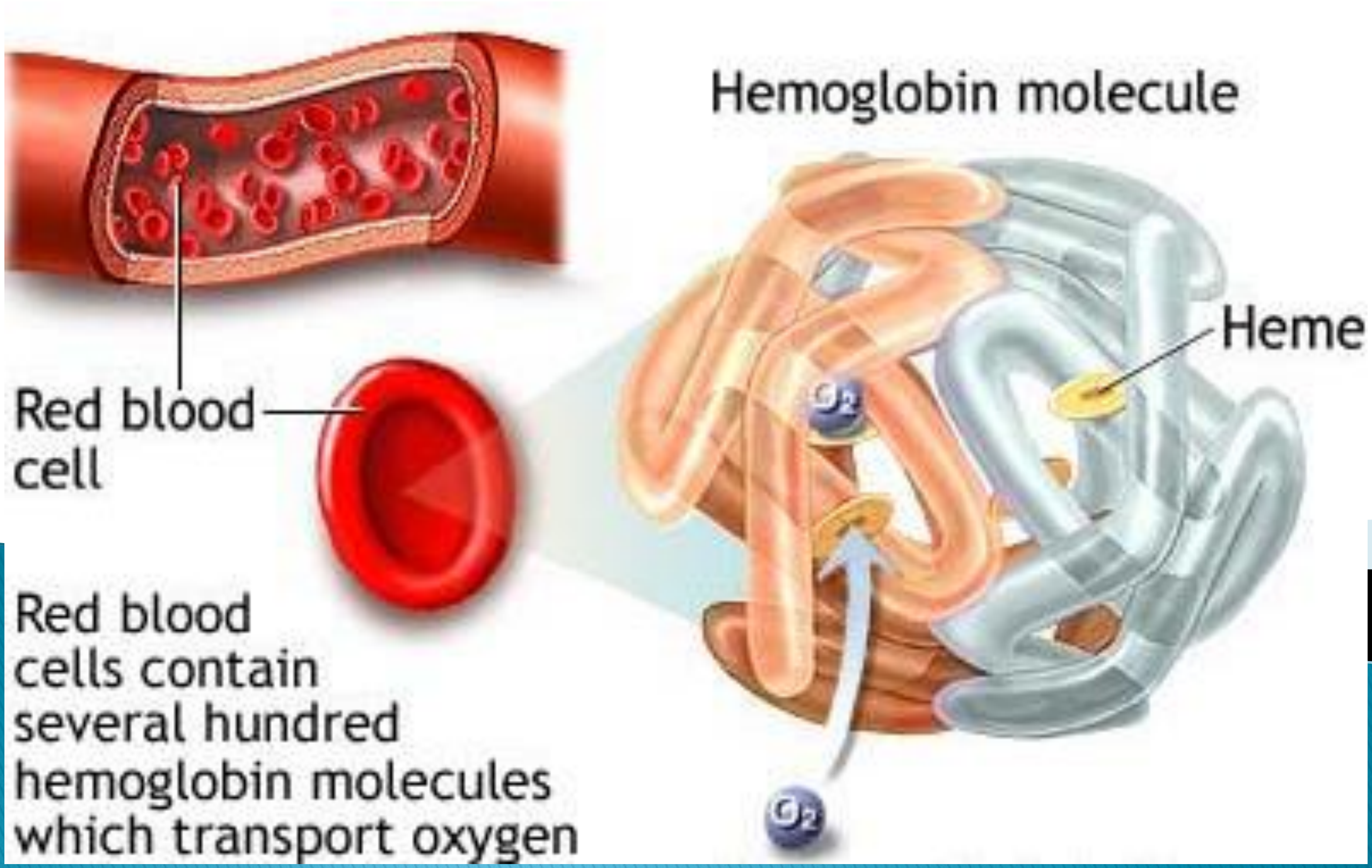




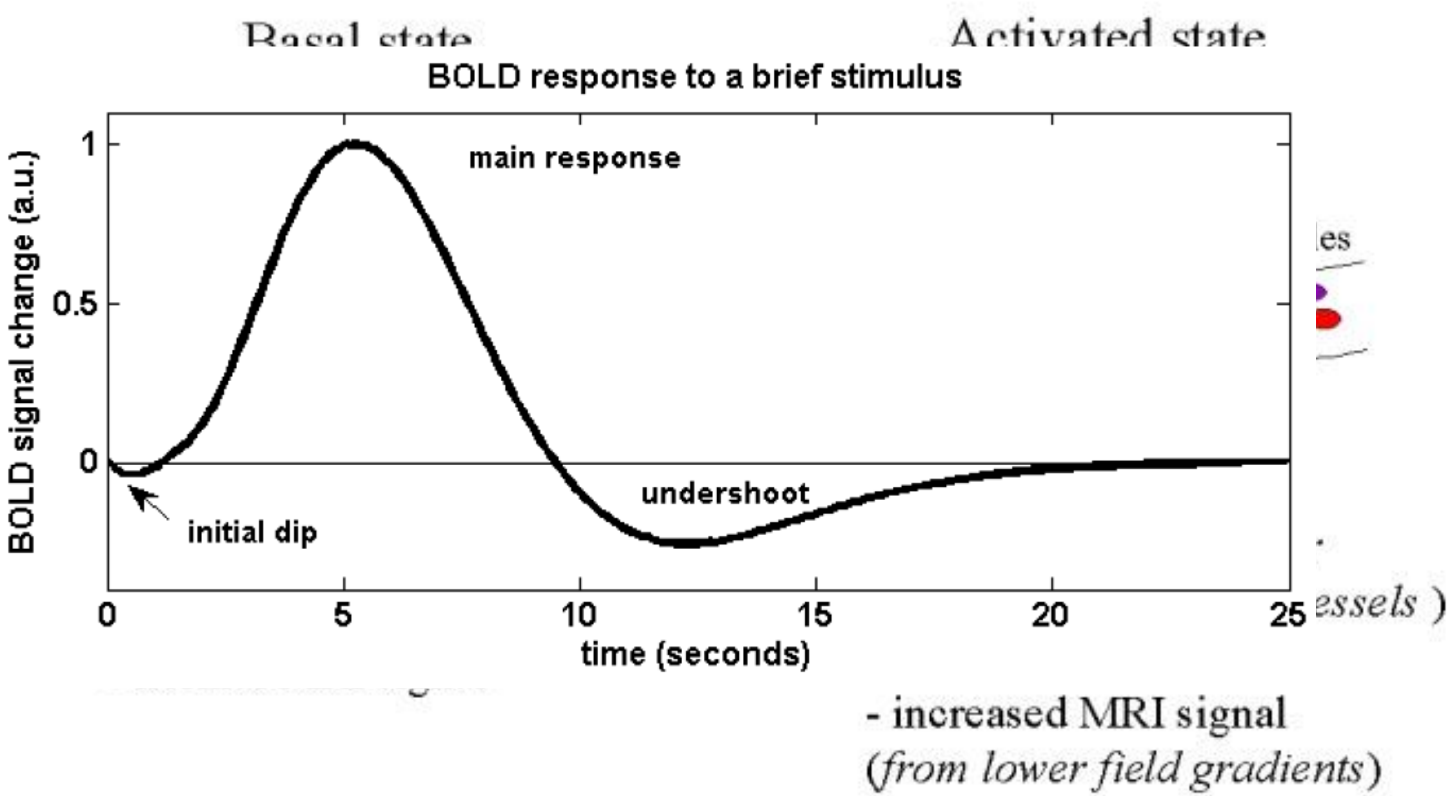


Finally, what is BOLD?

- Blood Oxygen Level Dependent signal
- O_2 is transported by haemoglobin (Hb)



BOLD: Hemodynamic Response Function



fMRI: From Physiology to Physics

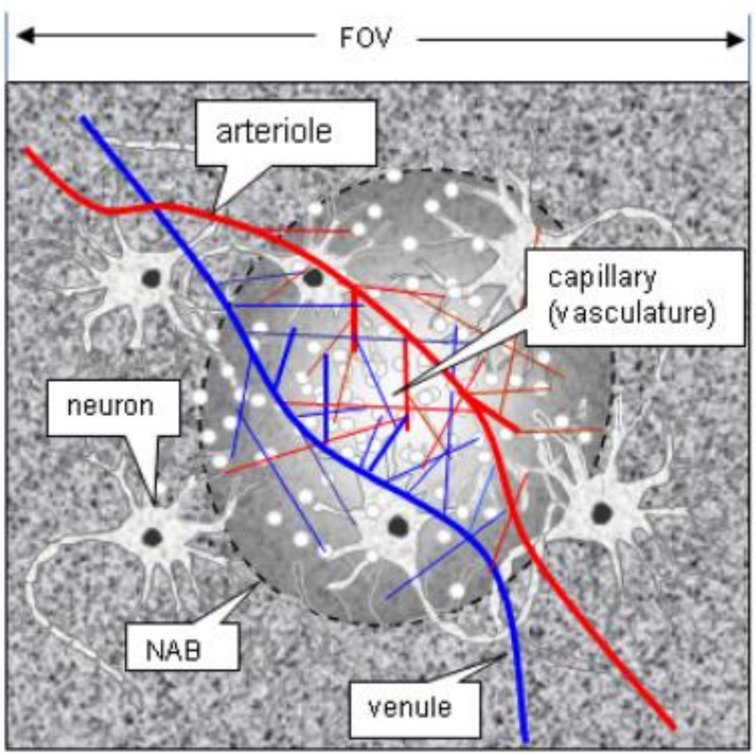
Neural Activity

PHYSIOLOGY

Hemodynamic Response

PHYSICS

MRI Contrast

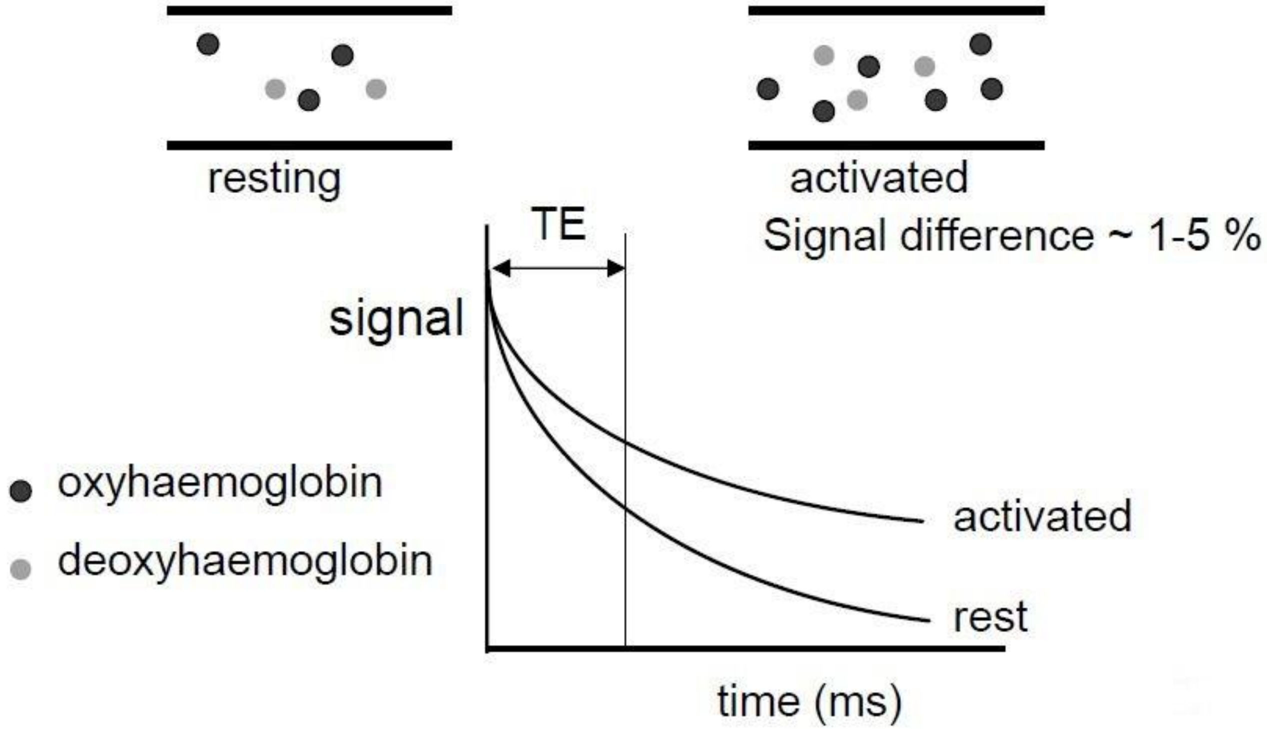


What is the difference between deoxyHb and oxyHb?

Remember T2* and field inhomogeneities?

DeoxyHb paramagnetic

strong field inhomogeneities



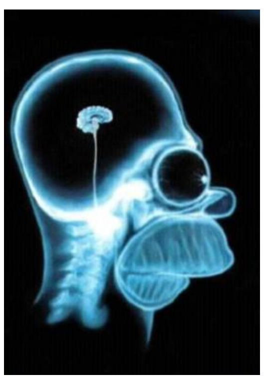
OxyHb diamagnetic

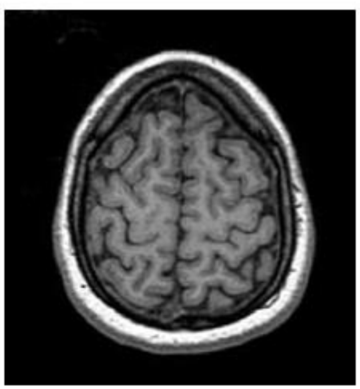
weak field inhomogeneities

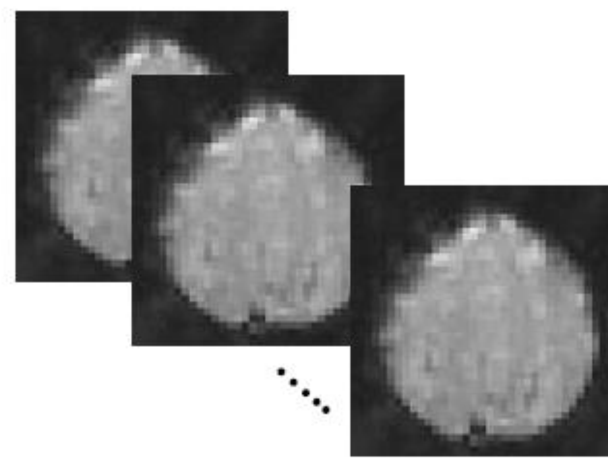
fMRI Data Acquisition

Difference Between MRI & fMRI

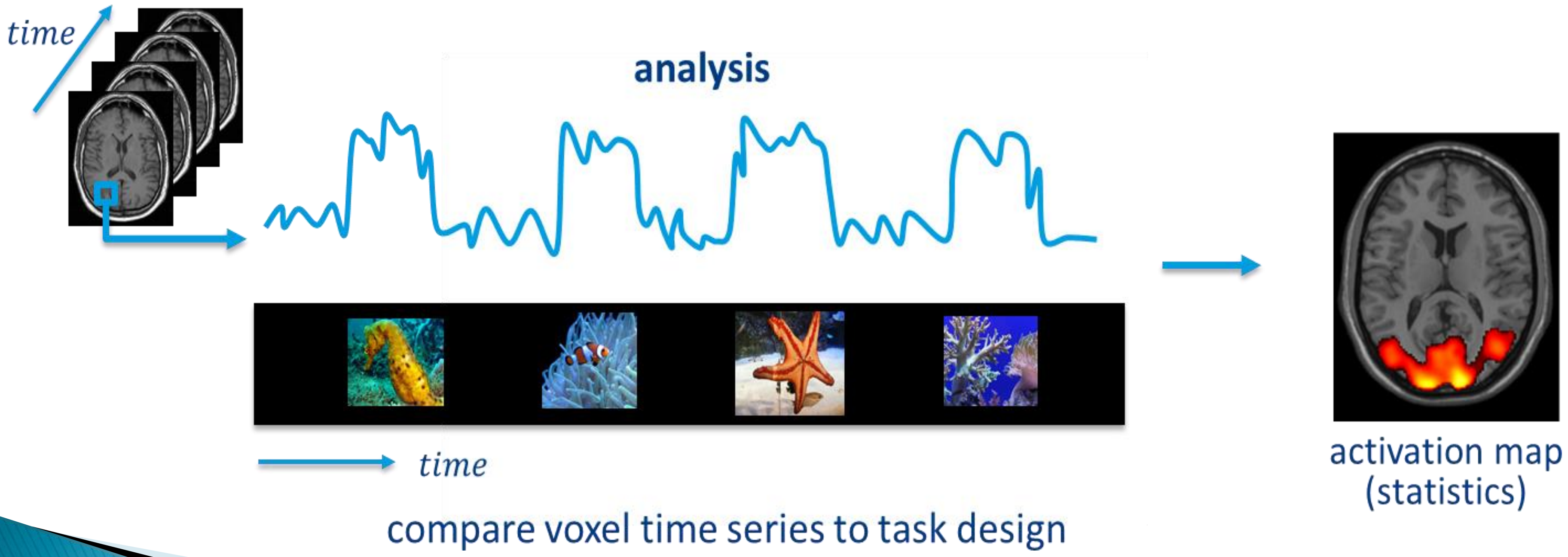
- MRI studies brain anatomy.
  - 3D with high spatial resolution
  - Can distinguish different types of tissue
- fMRI studies brain function.
  - Functional (T2*) images
  - 4D with lower spatial resolution but higher temporal resolution







- An fMRI experiment consists of a sequence of individual MR images, where one can study oxygenation changes in the brain across time



Data Acquisition Considerations

1) MRI physics
   - Optimal fMRI data acquisition is achieved through the consideration and refinement of many aspects of MRI imaging techniques.

2) General Issues in fMRI experimental design
   - The design of experiments reflects the temporal resolution of fMRI.
   - Task must be designed related to the experiment.

3) Scanner hardware and environment
   - The high magnetic field, restricted space and noise of scanner make special demands on the methods of stimulus presentation and subject accommodation within the system.

Tools Necessary for fMRI

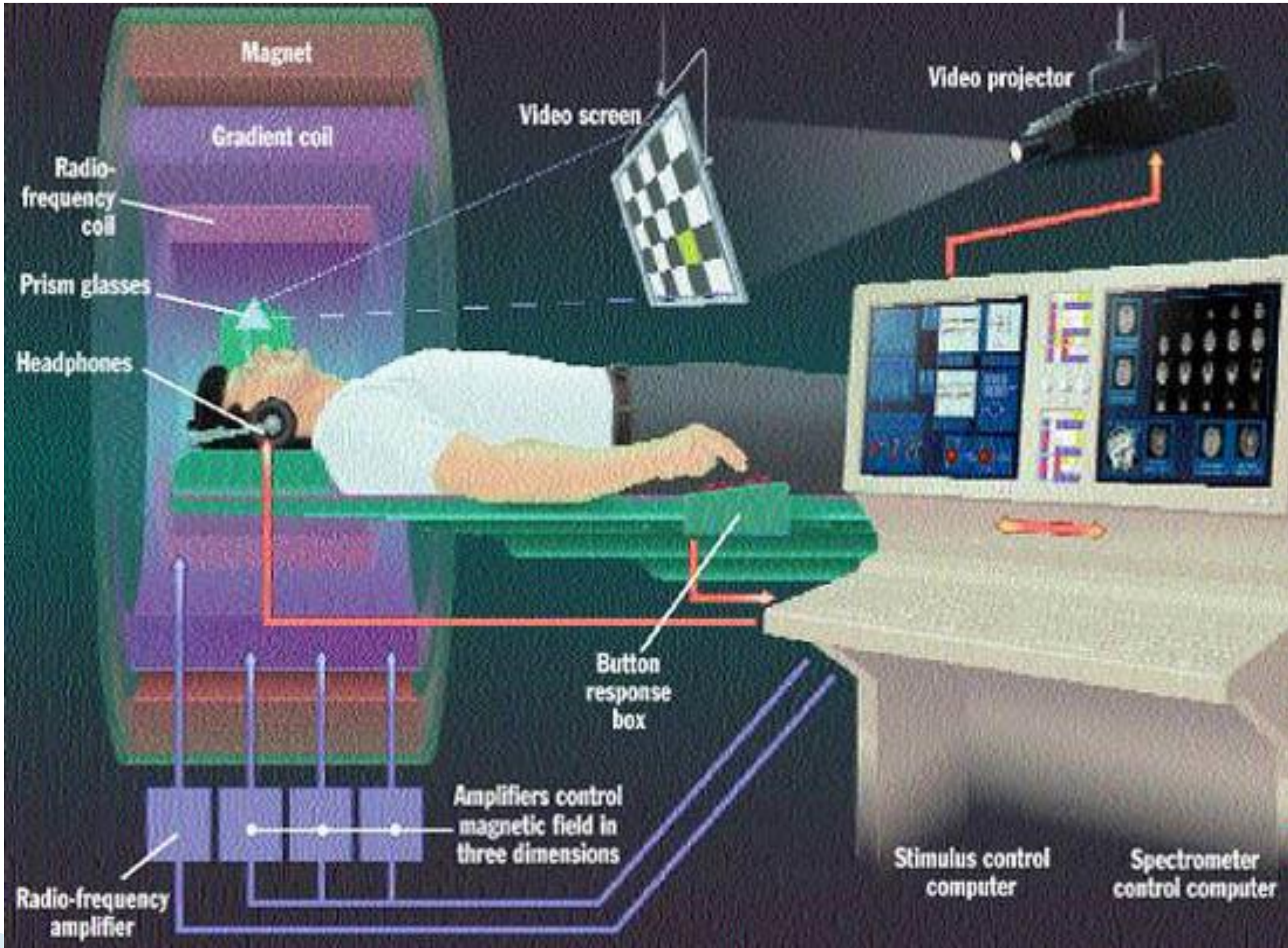
- **High-field MRI (1.5T or greater) scanner**
  BOLD effect (fMRI signal) increases with field strength

- **Fast pulse sequence**
  Echo Planar Imaging (GRE-EPI)

- **Stimulus presentation equipment**
  Projector to show visual stimuli
  Response devices such as button box to record subject's response
  Headphones for auditory stimuli (and hearing protection)

Experimental Design for fMRI

fMRI Experiment



fMRI Task Design

- Controlling the timing and quality of cognitive operations to influence resulting brain processes

- What can we control?

  Experimental comparisons (what is to be measured?)

  Stimulus properties (what is presented?)

  Stimulus timing (when is it presented?)

  Subject instructions (what do subjects do with it?)

Example : Motor Activation Task

What is to be measured? Motor Activation

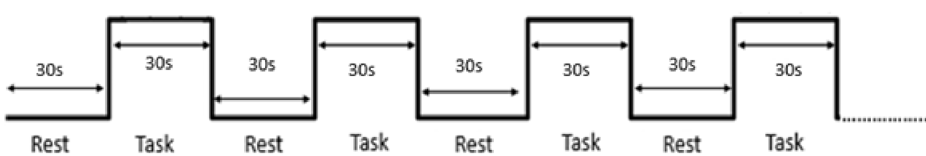
What is presented? Hand Picture

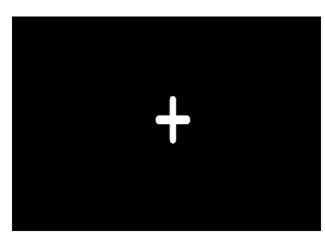
When is it presented? 30s-rest 30s-Act Total: 5 min

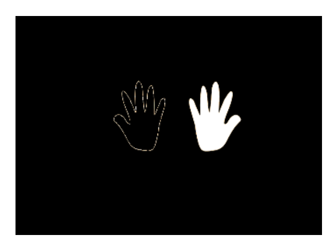
What do subjects do with it? Right finger tapping

Which MRI Protocol?

GE-EPI Sequence, Spatial & temporal resolutions (2.5*2.5*2.5 mm3 and 3s), brain coverage (Whole), TE & FA (30 ms & 90)



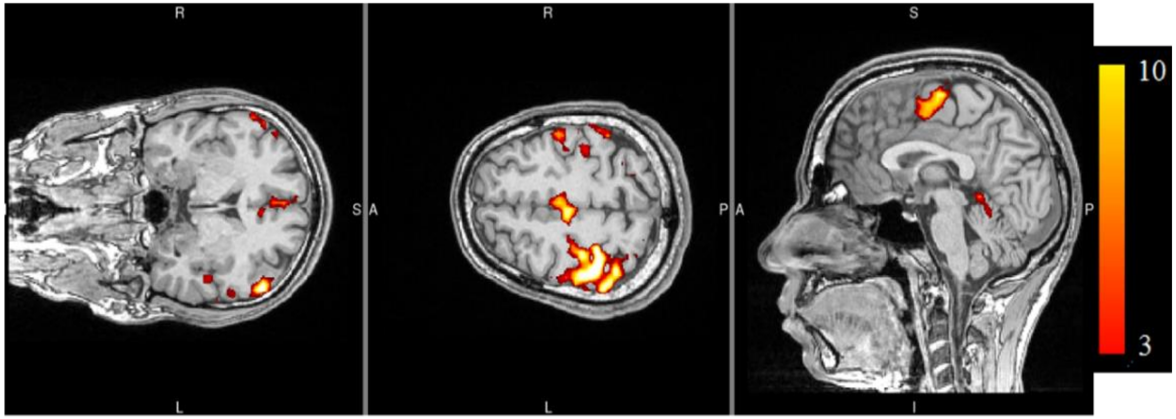




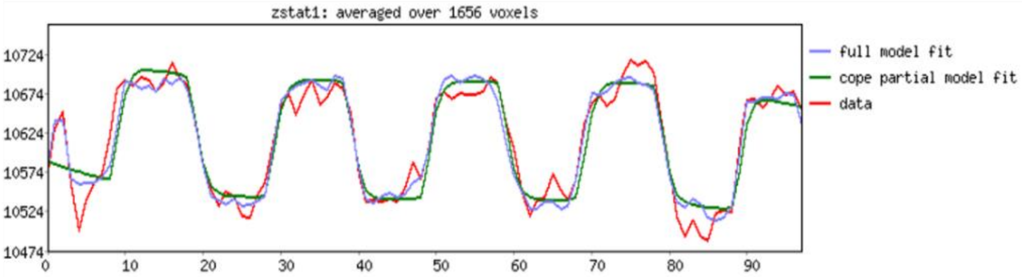
Example : Motor Activation Task

Result

Activation Map



Activation Signal Mean



Limitations of MRI scanner as a Psychophysical Lab.

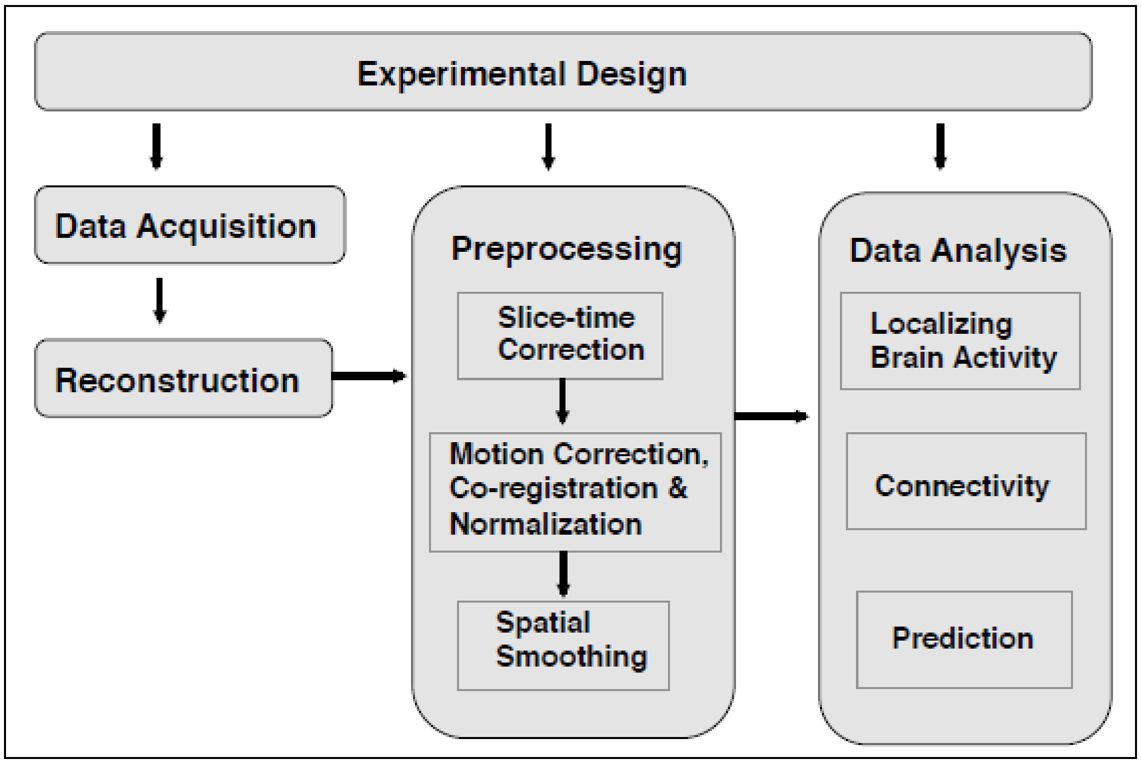
- Small space (limited room for equipments)
- Claustrophobia (patient)
- Strong magnet (some equipments won’t work)
- Limited range of motion (signal destruction)
- Scanner noise (care about auditory experiments)
- Fatigue (experiment duration)

Psychological Considerations

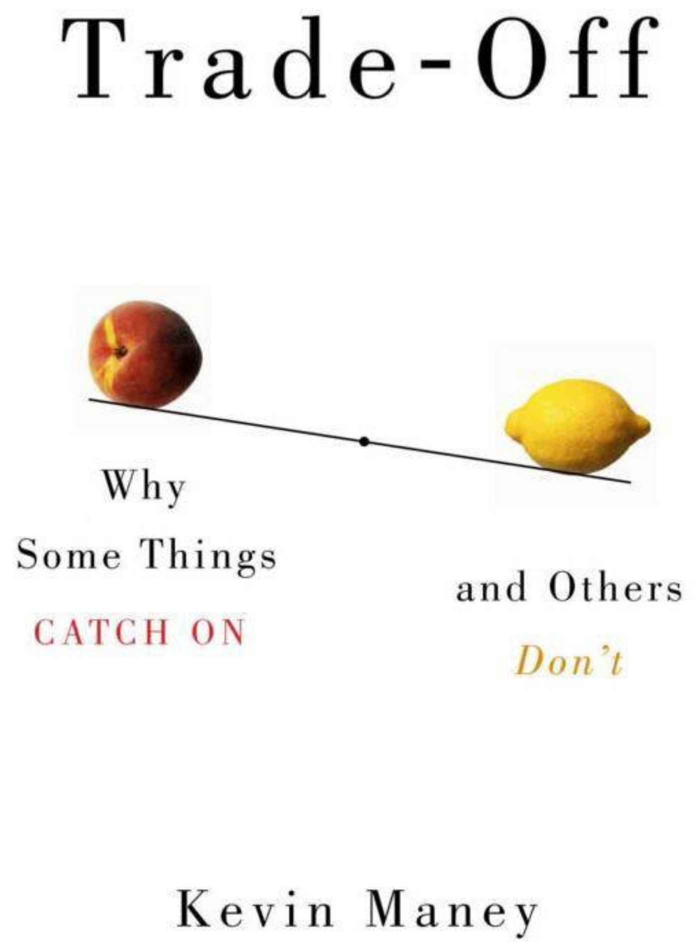
- It is important that the task induces the subject to think or perform in the intended manner.
  - Don’t make the study too predictable as this may influence the subjects psychological state.
  - Make sure to keep subjects on task by giving them just the right amount of time to perform it.
  - What you expect from subjects should fit with what they can actually do.

  - Keep in mind that subjects’ brains may be responding to things you didn’t tell them to do.

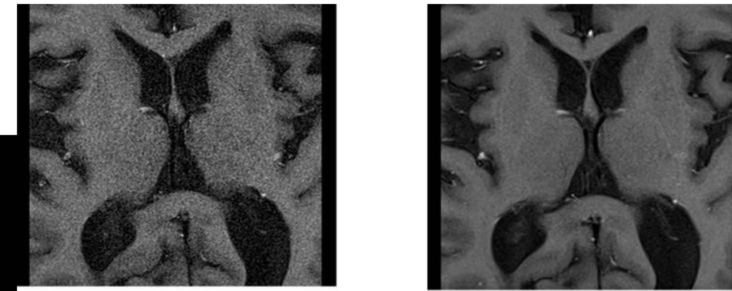
Data Acquisition and Processing Pipeline

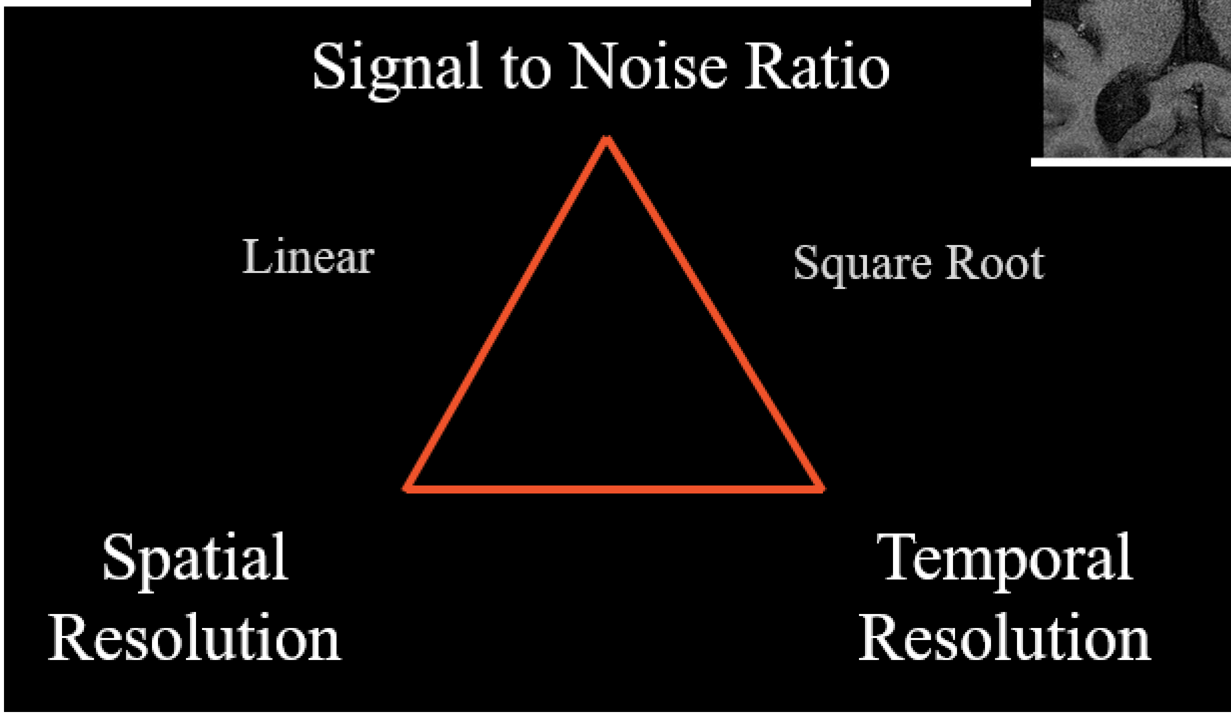


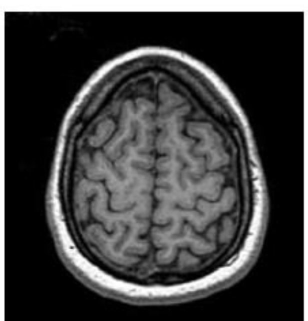
VERY IMPORTANT POINT
YOU SHOULD KEEP IN MIND ABOUT MRI & fMRI

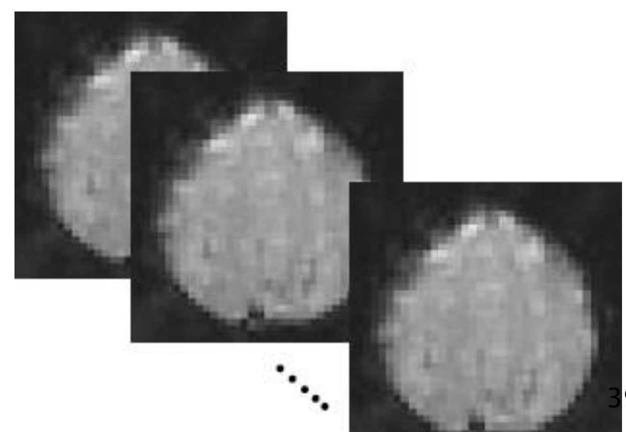


TRADE-OFF in MRI









TRADE-OFF fMRI

Magnetic Resonance Imaging 50 (2018) 17–25

Contents lists available at ScienceDirect

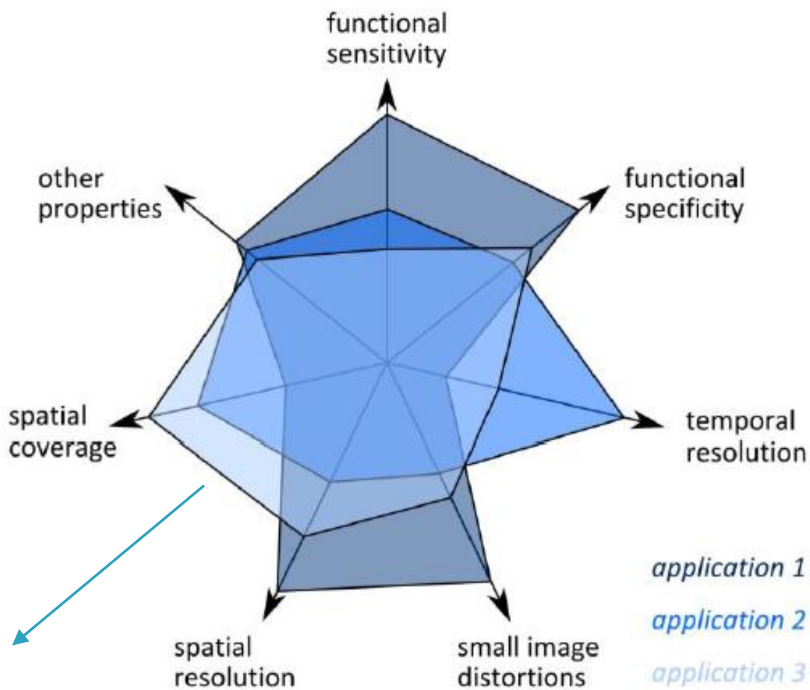
Magnetic Resonance Imaging

journal homepage: www.elsevier.com/locate/mri

A robust SSFP technique for fMRI at ultra-high field strengths

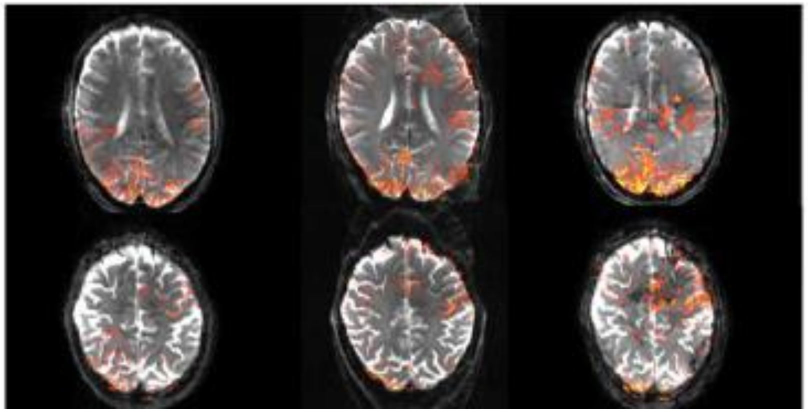
Vahid Malekian[a], Abbas Nasiraei Moghaddam[a,*], Mahdi Khajehim[a,b]

[a] Department of Biomedical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[b] School of Cognitive Sciences, Institute for Research in Fundamental Sciences, Tehran, Iran



Analysis

CE-FAST SE EPI bSSFP



Specificity vs. Sensitivity

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Journal of Neuroscience Methods

journal homepage: http://ees.elsevier.com

Efficient de-noising of high-resolution fMRI using local and sub-band information

Vahid Malekian[a,b], Abbas Nasiraei-Moghaddam[a,b,*], Amir Akhavan[c], Gholam-Ali Hossein-Zadeh[b,d]

[a] Department of Biomedical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[b] School of Cognitive Sciences, Institute for Research in Fundamental Sciences, Tehran, Iran
[c] Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
[d] School of Electrical and Computer Engineering, University College of Engineering, University of Tehran, Tehran, Iran

Spatial-resolution vs. Sensitivity

Future of fMRI…

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NeuroImage

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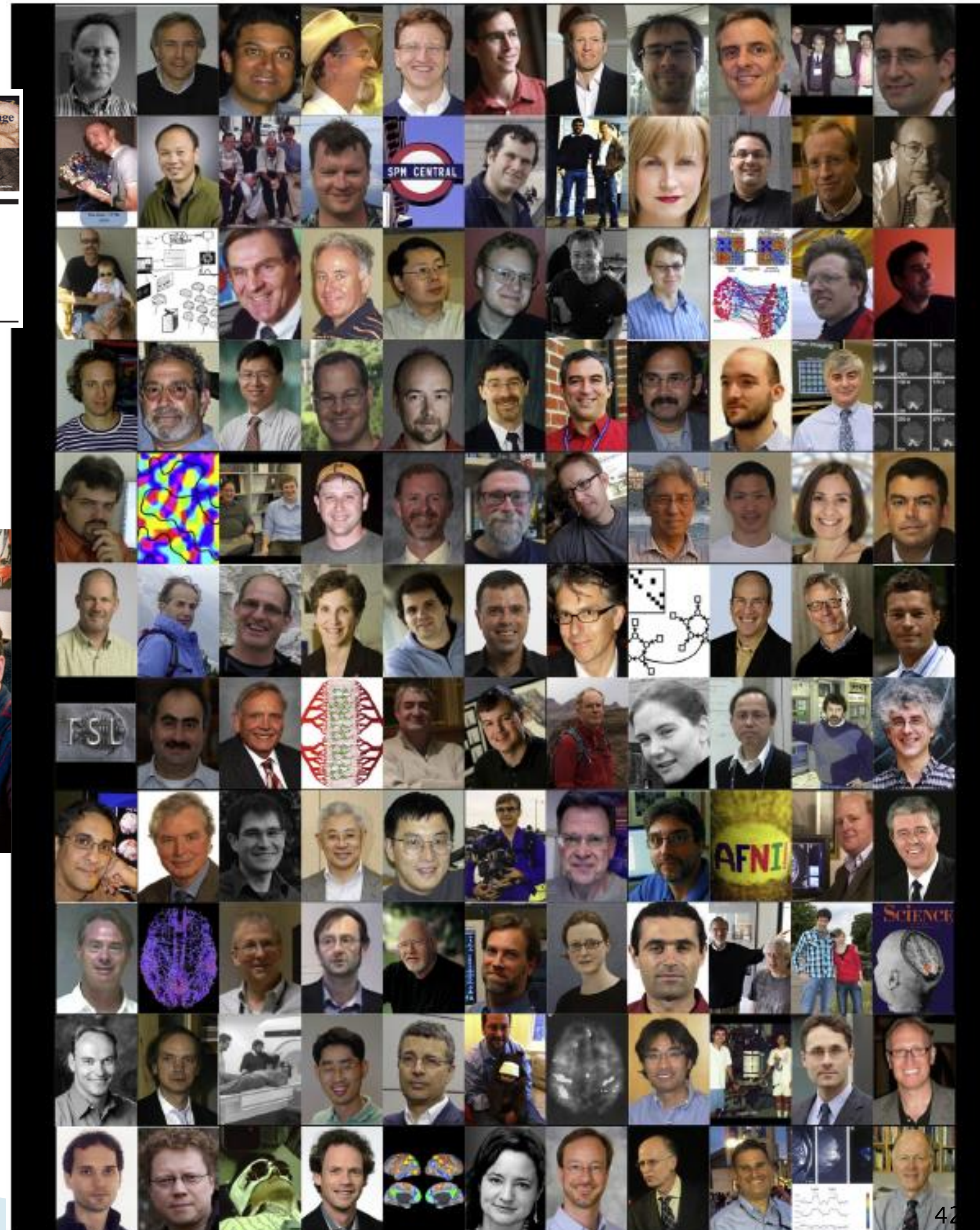
Review

Twenty years of functional MRI: The science and the stories

Peter A. Bandettini *

Section on Functional Imaging Methods and Functional MRI Core Facility, National Institute of Mental Health, Bethesda, MD, USA



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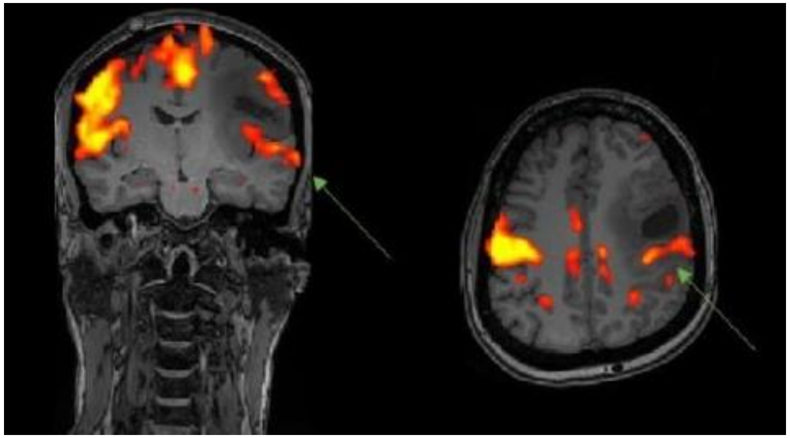
	91	The history of the future of the Bayesian brain	Karl Friston
	92	Quantitative functional MRI: concepts, issues, and future challenges	Bruce Pike
	93	The future of ultra-high field MRI and fMRI for study of the human brain	Jeff Duyn
	94	Seeing patterns through the hemodynamic veil — the future of pattern-information fMRI	Niko Kriegeskorte and Elia Formisano
	95	The future of fMRI connectivity	Steve Smith
	96	The future of fMRI in clinical medicine	Ed Bullmore
	97	Future trends in neuroimaging: neuronal processes as expressed within real-life social contexts	Uri Hasson
	98	The future of fMRI with perfusion imaging	Geoff Aguirre
	99	The future of fMRI and genetics research	Andreas Meyer-Lindenberg
	100	The future of functionally related structural change assessment	Heidi Johansen-Berg
	101	The future of the human connectome	David van Essen and Kamil Ugurbil
	102	The future of susceptibility contrast for assessment of anatomy and function	Jurgen Reichenbach
	103	fMRI at 20: has it changed the world?	Bruce Rosen

fMRI Research Lines

- Data acquisition and reconstruction
  - Developing fMRI techniques for higher spatial and temporal resolutions
  - Contrast improvement

- Data Processing
  - De-noising & enhancement
  - Advanced functional analysis



- fMRI Clinical Applications
  - Quantitative assessments for the treatments
  - Pre-surgical planning for tumor patients
  - Alzheimer, dementia, ADHD, epilepsy …

Motor Mapping for Pre-surgical Planning Using Seed-based Resting-State fMRI Approach

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2) Department of Biomedical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

- Physics & Engineering
  - Simulations
  - Hardware (coil design & peripherals)

- Multimodal imaging

  EEG-fMRI, MEG-fMRI and fNIR-fMRI

A journey of a thousand miles must begin with a single step.

Lao Zi

Thank you …